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MEMORANDUM REPORT ARBRL-MR-03160

(Supersedes IMR No. 705)

# EFFECT OF GUN TUBE EVACUATION ON FREE FIELD BLAST PRESSURES AND COMPARISON WITH PROPOSED MODELS



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March 1982

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BALLISTIC RESEARCH LABORATORY
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# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

**1. REPORT NUMBER**
MEMORANDUM REPORT ARBRL-MR-03160

**2. GOVT ACCESSION NO.**

**3. RECIPIENT'S CATALOG NUMBER**

**4. TITLE (and Subtitle)**
EFFECT OF GUN TUBE EVACUATION ON FREE FIELD BLAST PRESSURES AND COMPARISON WITH PROPOSED MODELS

**5. TYPE OF REPORT & PERIOD COVERED**
Final

**6. PERFORMING ORG. REPORT NUMBER**

**7. AUTHOR(s)**
Raymond E. Gordnier

**8. CONTRACT OR GRANT NUMBER(s)**

**9. PERFORMING ORGANIZATION NAME AND ADDRESS**
US Army Ballistic Research Laboratory
(ATTN: DRDAR-BLL)
Aberdeen Proving Ground, MD 21005

**10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS**
RDT&E 1L161102AH43

**11. CONTROLLING OFFICE NAME AND ADDRESS**
US Army Armament Research & Development Command
US Army Ballistic Research Laboratory (DRDAR-BL)
Aberdeen Proving Ground, MD. 21005

**12. REPORT DATE**
March 1982

**13. NUMBER OF PAGES**
33

**14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)**

**15. SECURITY CLASS. (of this report)**
Unclassified

**15a. DECLASSIFICATION/DOWNGRADING SCHEDULE**

**16. DISTRIBUTION STATEMENT (of this Report)**

Approved for public release; distribution unlimited.

**17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)**

**18. SUPPLEMENTARY NOTES**

This report supersedes Interim Memorandum Report No. 705 dated March 1981.

**19. KEY WORDS (Continue on reverse side if necessary and identify by block number)**

Muzzle Blast
Shock Waves
Aerodynamic Interactions
Unsteady Flow

**20. ABSTRACT (Continue on reverse side if necessary and identify by block number)** (ner)

Since excessive muzzle blast overpressures are adversely affecting artillery crew safety and performance, there is interest in developing a detailed understanding of the blast from guns, so that accurate computations may be performed and blast prediction techniques may be developed. The objective of this paper is to examine the influence of the precursor flow upon the propellant gas blast. To investigate the precursor effect, a 20mm cannon is evacuated to eliminate the air column forward of the projectile. (Continued)

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Data taken from these rounds are compared with that from firings at ambient conditions. The precursor-propellant gas interaction is demonstrated to influence the blast wave development in the near field forward of the muzzle; however, beyond a distance of 25 calibers from the muzzle, the two cases are indistinguishable.

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# I. INTRODUCTION

Excessive blast overpressures at crew stations presently restrict the use of several Army weapons systems. Similarly, proving grounds often have to curtail operation during certain atmospheric conditions which allow blast focusing on populated areas. Many gun systems have muzzle devices whose use and effectiveness are influenced by their muzzle flow. Recently, an interest has arisen in the study of muzzle flash and secondary flash. These problems lead to the need for a more detailed understanding of the muzzle flow and the blast overpressure fields.

The flow from the muzzle of a gun consists of two impulsive jets (Figure 1). The air being forced out ahead of the projectile creates the first flow, called the precursor flow. As the projectile exits the gun tube, the high pressure, propellant gases are released creating a second, propellant gas flow. This flow rapidly overtakes and effectively consumes the much weaker precursor flow.

A variety of research projects have already been carried out to investigate the previously mentioned problems. In a series of optical experiments, Schmidt and Shear[1] characterized the muzzle flow around small caliber weapons. Erdos and Del Guidice[2] have developed a spherically symmetric model which calculates flow properties along the axis of symmetry. Their model assumes a core flow that is prediced by a steady method of characteristics calculation and then uses a finite difference technique to calculate the propagation of the shock layer between the jet Mach disk and the blast wave. Westine[3], Smith[4], and Schmidt[5] have each presented a scaling law used to predict overpressures in the muzzle blast field. Fansler[6] extends the scaling law of Smith to incorporate a more general range of weapons.

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1. *E. M. Schmidt and D. D. Shear, "Optical Measurements of Muzzle Blast," AIAA Journal, Vol. 13, No. 8, August 1975, pp. 1086-1091.*

2. *J. Erdos and P. Del Guidice, "Calculations of Muzzle Blast Flow Fields," AIAA Journal, Vol. 13, No. 8, August 1975, pp. 1048-1056.*

3. *P. Westine, "The Blast Field About the Muzzle of Guns," Shock and Vibration Bulletin, Vol. 39, Part 6, March 1969.*

4. *F. Smith, "A Theoretical Model of the Blast from Stationary and Moving Guns," 1st International Symposium on Ballistics, Orlando, FL, November 1974, sponsored by American Defense Preparedness Association, Washington, D.C. 20005.*

5. *E. M. Schmidt, G. D. Kahl, and D. D. Shear, "Gun Blast: Its Propagation and Control," AIAA Paper 80-1060, June 1980.*

6. *K. S. Fansler and G. Keller, "Variation of Free-Field Muzzle-Blast with Propellant Type," 6th International Symposium on Ballistics, Orlando, FL, October 1981, sponsored by American Defense Preparedness Association, Washington, D.C. 20005.*

In a paper by Schmidt, Kahl, and Shear[5], it is suggested that the precursor flowfield affects the development of the propellant blast field. The present report presents a more detailed look at the interaction between the precursor and the propellant gas flows. By evacuating the gun tube ahead of the projectile, the precursor is eliminated. Comparison of these firings with normal or ambient conditions permits the isolation of the influence of the precursor flow. The near field is observed through a series of spark shadowgraphs while far-field data is acquired with static or side-on pressure transducers. The experimental results are compared with the scaling relations of Schmidt[5] and Fansler[6]. Additionally, a separate development is presented which extends the results of Erdos[2] away from the axis of symmetry.

## II. TEST INSTRUMENTATION AND TECHNIQUE

The weapon fired in this program is a 20mm cannon (Figure 2) which has a barrel length of 1.52m, a chamber volume of 41.7cm$^3$ and a twist of rifling of one turn in 25 calibers. An M55A2 training round weighing 98g and having a L/D of 3.75 is used. The propellant fired is WC870 which has the following properties:

$$RT_{ad} = 9.87 \times 10^5 \ m^2/s^2$$

$$\gamma = 1.24$$

Rounds are fired at reduced charges to obtain a range of exit conditions, summarized below:

| $m_c$(g) | $V_e$(m/s) |
|---|---|
| 3.6 | 280 |
| 17.8 | 610 |
| 38.9 | 1060 |

To investigate the effects of the tube gases ejected prior to projectile separation, the gun tube is evacuated before firings, thus effectively eliminating the precursor flow. Placing a mylar diaphragm across the muzzle and an "O" ring around the projectile forward of the rotating band allows the gun tube to be evacuated to below 50μm of Hg before firing.

Static pressure transducers placed along rays of 10°, 45°, 90°, 135°, and 170° measure the pressure pulses in the blast field. A spark shadowgraph technique[1] permits the observation of the muzzle flowfield. However, optical and transducer surveys are made separately to minimize the effect of reflecting from the Fresnel lens. Approximately three rounds are fired at each set of pressure transducer locations. Data is acquired for both the ambient and evacuated tube cases.

## III. MUZZLE FLOW ANALYSIS

As previously mentioned, the muzzle flow development is observed through a series of spark shadowgraphs. The early development of the flow is portrayed in Figure 3. The projectile has just separated from the gun bore and the high pressure propellant gases are escaping. For the atmospheric case (Figure 3a), the precursor flow is clearly portrayed and the development of the blast caused by the propellant gases has been slowed due to its submergence in the hot and turbulent gases of the precursor flow. By contrast, the evacuated case (Figure 3b), shows that the precursor has been almost completely eliminated. What remains appears to have little influence on the development of the main blast.

In Figures 4 and 5, the development of the blast wave can be seen. The atmospheric case, Figures 4a and 5a, clearly shows the effect of the precursor on the development of the blast in the axial direction. The blast wave is propagating into a preconditioned medium with a high velocity and a higher temperature, which allows the forward portion of blast to move out more rapidly than the lateral portions. This creates a nonspherical shape as opposed to the more spherically symmetric blast for the evacuated case (Figures 4b and 5b).

Finally, in Figure 6 the blast wave is fairly well developed and for the atmospheric case the blast wave is about to overtake the precursor wave (Figure 6a). As the blast wave overtakes the precursor wave it becomes fully developed and rapidly approaches the shape corresponding to the evacuated case (Figure 6b).

## IV. BLAST FIELD ANALYSIS

The effect of evacuating the tube can be seen in Figure 7. The peak overpressures along a $\phi = 10^\circ$ radial described by

$$\overline{\Delta p} = (p-p_\infty)/p_\infty \qquad (1)$$

are plotted for both atmospheric and evacuated conditions fired at a projectile velocity, $V_p$ = 1060m/s. At locations near the muzzle, higher overpressures are obtained for rounds fired from an evacuated gun tube. Indicating that, in the ambient firings, interactions between the expanding propellant gas and the precursor flow cause an attenuation in the strength of the air shock. Further from the muzzle ($R/D \geq 30$), the overpressure levels are indistinguishable.

The pressure data taken with the ambient tube (Figure 7) displays a number of interesting features which may be correlated with properties of the flow field through observation of the spark shadowgraph sequences. Between 5 and 10 calibers from the muzzle, the overpressure profile has a local minimum. At 5 calibers the propellant gas wave is still immersed in the supersonic core of the precursor jet; however by 7.5 calibers, the blast wave moves outside of the supersonic core. Within the precursor jet, the propellant gas is expanding into an ambient with a high wave speed in the axial direction. This reduced the strength of the shock developed ahead of the propellant gas/air interface. However, once the propellant gas expands through the precursor jet, the nature of the surroundings change. The expansion now occurs in a relatively quiescent, lower wave speed ambient with a resultant increase in shock strength as the interface is penetrated.

Beyond 10 calibers, the pressures for the atmospheric case become larger than those for the evacuated case. A possible explanation for this behavior is that at this location, the blast generated by the release of the propellant gases coalesces with the precursor blast. In both the evacuated and ambient data, a local maximum in overpressure is observed at R/D = 22.5. This is due to an interaction between the air blast and projectile shock system as the round moves free of the decelerating blast.

Figure 8 presents a similar set of data for a $\phi = 45°$ radial. The precursor has little effect on the blast overpressures. Peak overpressures along a $\phi = 90°$ radial are presented in Figure 9. In this case, effects of the precursor do not appear significant. The data indicates that, as would be expected, the influence of the precursor flow is greatest near the line of fire and confined to the region close to the muzzle. However, since most existing analytical and numerical treatments of the muzzle flow do not include the precursor/propellant gas interaction, it is important to be aware of this phenomena when making comparisons between theory and experiment. Theory would produce a description of a flow field more nearly corresponding to the current evaluated tube data and should tend to over-predict blast pressure in the near field. Such over-predictions may not be a serious problem. If used to describe peak pressure levels on a muzzle device, the analysis would produce a built-in safety factor for the estimation of stress levels. In the far field, where crew members are present, the analysis and experiment should show minimal sensitivity to precursor effects.

## V. MUZZLE BLAST MODELING

In this section, the measured blast overpressure properties of the 20mm cannon are compared with existing analyses[2,5,6]. The numerical calculations of Erdos and Del Guidice[2] describe the muzzle flow in a region close to the axis of symmetry. In the present comparison, the predicted variation of pressure along the axis is swung to different rays by using the scaling law of Smith[4].

Smith presents the following expression for the variation of scale length with the azimuthal angle, $\phi$:

$$\frac{c'}{c} = f \cos \phi + (1 - f^2 \sin^2 \phi)^{\frac{1}{2}} \tag{2}$$

Smith develops this relationship from an analogy between the blast from a gun and that from a moving explosion. The value c' is in effect a stretched reference length, whereas c is the representative length of the gun. The parameter f is calculated from the best fit between c' and $\phi$. The values of c' were calculated from data given by Schmidt[5] and the following equation given by Smith[4].

$$\overline{\Delta p} \propto (c')^{4/3} \tag{3}$$

For the 20mm gun used in these tests, f is determined to be 0.79.

The results of these calculations along a 10° ray are presented in Figure 10a. The predictions give reasonable results for locations greater than 12.5 calibers. Also, as expected, the predictions in the near field tend to agree with the evacuated tube data since the numerical calculation does not account for the effects of the precursor. Figure 10b presents a similar set of results for a 90° ray. In this instance, the procedure results in predictions which are reasonable for the reduced velocity cases but do not agree well for $V_m$ = 1060m/s.

Schmidt[5] suggests method for predicting the blast overpressure which uses the stabilized position of the Mach disk, $x_{ns}$, as a reference length. Schmidt gives the following equation for the variation in overpressure

$$\overline{\Delta p} = 0.975 \quad \Phi/\overline{r}^{-1.1} \tag{4}$$

where

$$\Phi = .8 \cos\phi + (1 - .64 \sin^2\phi)^{\frac{1}{2}} \tag{5}$$

$$\overline{r} = r/x_{ns} \tag{6}$$

A comparison of Schmidt's predictions using the measured position of the Mach disc[5] is presented in Figure 11. While obtaining general agreement with measurement, the scaling technique tends to over-predict pressure levels.

Fansler and Keller[6] have developed a predictive scheme based on the work of Smith[4] which permits calculation of blast overpressure contours once the interior ballistic performance of the weapon is determined. The basic relation describing overpressure is

$$\overline{\Delta p} = F \ (c'/c)/(r/\ell)^{\underline{n}} \tag{7}$$

where c'/c is given by Smith's expression for the variation in scale length with polar angle, Equation (2), and, for best agreement, F and n are found to be 1.65 and 1 respectively. The scale length is given as

$$\frac{\ell}{D} = \sqrt{\frac{EM_p}{100 \ (U - \eta c) \ p_\infty \ [1+c/3m_1]}} \tag{8}$$

where $M_p = V_p/a_e$, U is the volume of the chamber plus bore volume, c is the mass of the propellant charge, and $m_1$ is the mass of the projectile if friction is taken into account. The covolume, $\eta$, is approximated by the value 1.2 x $10^{-3}$ $m^3$/kg. Further, the quantity E, the original internal energy minus the kinetic energy of the projectile and propellant and the heat losses to the surroundings is

$$E = \frac{BCRT_a}{\gamma - 1} - \frac{1}{2} (m_1 + c/3) \ (1+x) \ V_p^{\ 2} \tag{9}$$

where B is the percent of propellant burnt and x is the ratio of heat losses to the kinetic energy. Combining these expressions with Equation (7), yields the final equations for overpressure with sonic exit flow

$$\overline{\Delta p} = \frac{0.165[0.8 \cos\theta + (1-0.64 \sin^{-2}\theta)^{\frac{1}{2}}]}{r/D} \quad \frac{EM_p}{(U-\eta c)\ p_\infty[1+c/(3m_1)]} \tag{10}$$

and with supersonic exit flow

$$\overline{P}_s = 0.94\ \overline{p}\sqrt{\{1 + [1+c/(3m_1)]\ c\ V_p^{\ 2}\}/(2E)} \tag{11}$$

Comparison of the predictions with experimental data shows that good agreement is obtained although the predicted rate of decay of overpressure in the far field is somewhat greater than measurements.

## VI. CONCLUSIONS

A set of data has been taken to investigate the precursor/propellant gas interactions. It is shown that the precursor seems to have a significant effect on the muzzle flow near the gun bore axis, but this effect decreases with azimuthal angle. In the far field, the precursor has no measured effect on the blast field.

Three techniques for predicting blast overpressures are compared with experimental results. The method proposed by Fansler gives good agreement with the data, requires minimal effort, and is sensitive to changes in weapon ballistics.

## ACKNOWLEDGMENT

The author wishes to thank Donald McClellan, William Thompson, and Gary Rumley for their aid in the preparation and operation of this test program. This writer also acknowledges the guidance of Drs. E. M. Schmidt and K. S. Fansler in the development of this research effort.

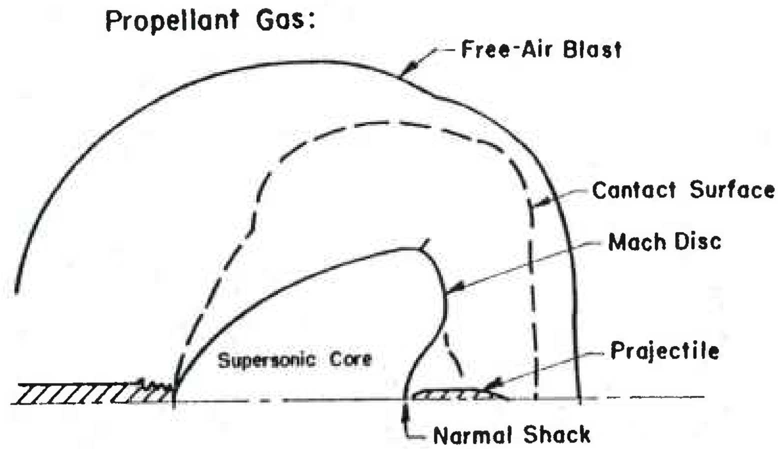



FIGURE 1 FLOW FIELD SCHEMATICS

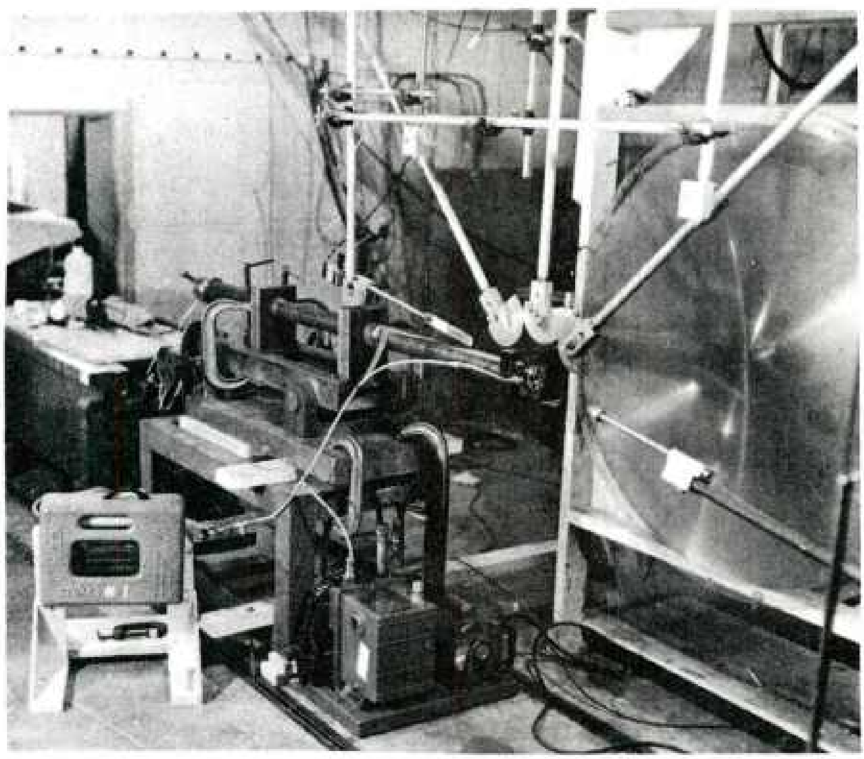
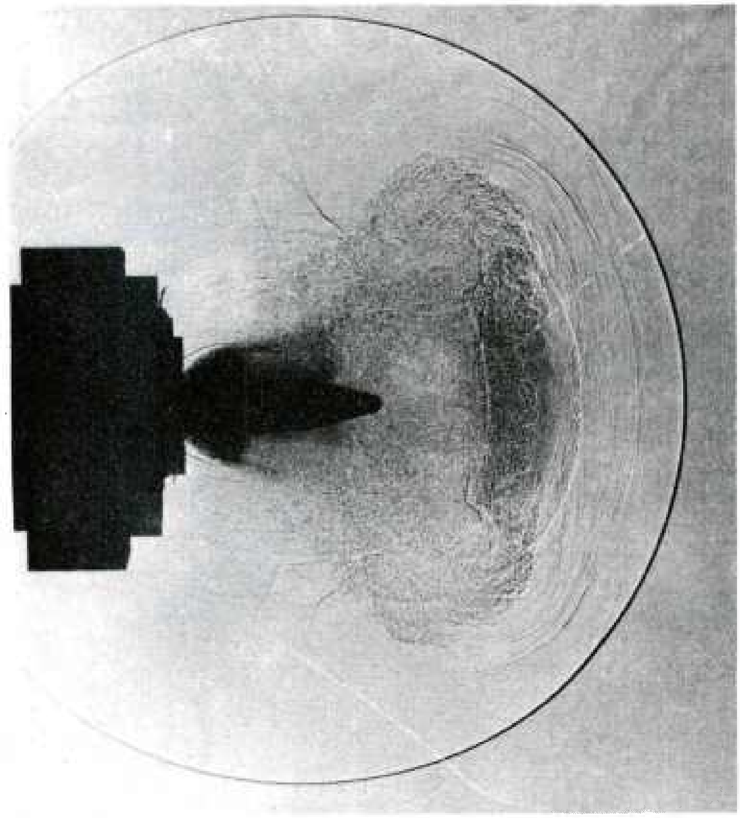
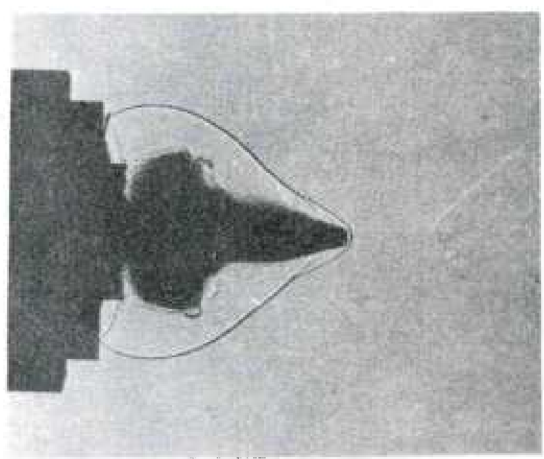


Figure 2. Experimental Instrumentation

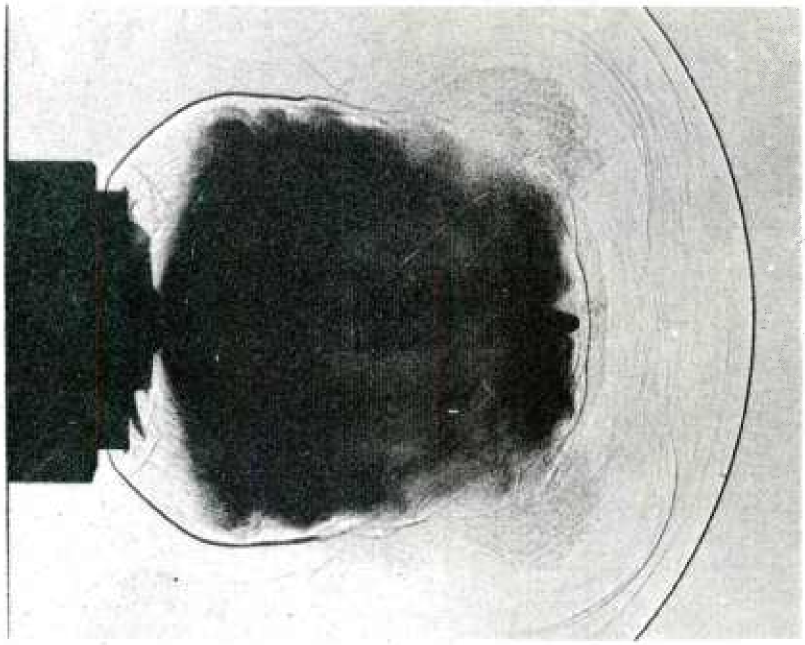


a. Atmospheric Tube



b. Evacuated Tube

Figure 3. Comparison of Muzzle Flow Development - Example 1



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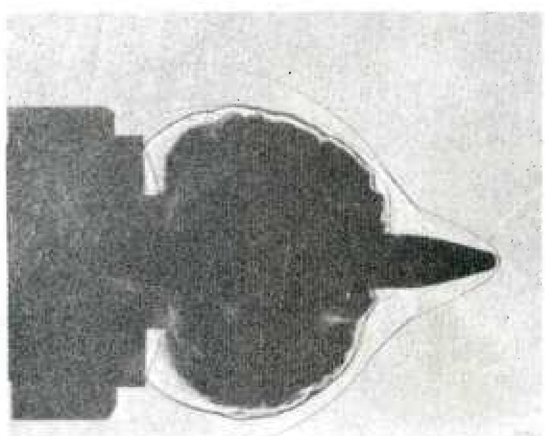
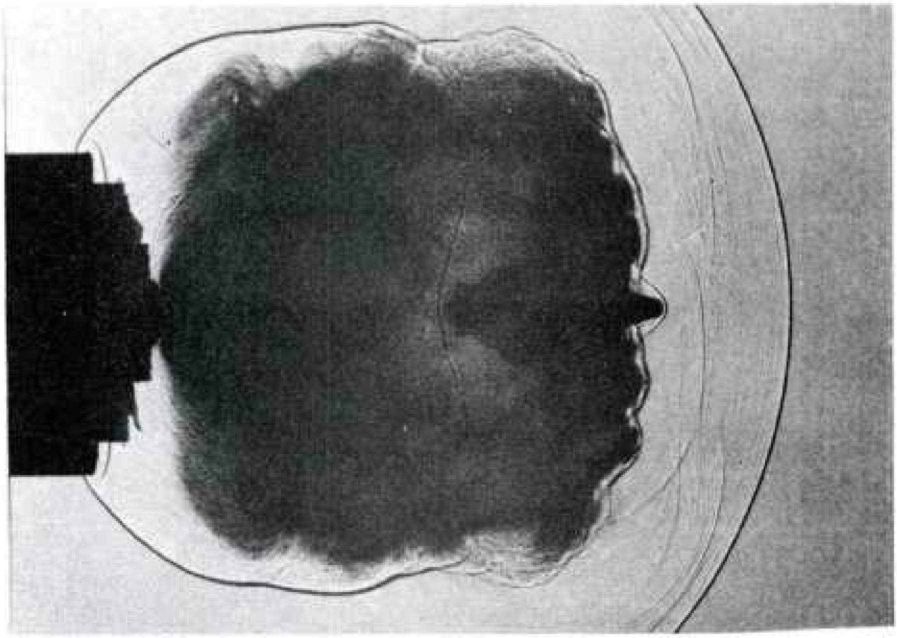
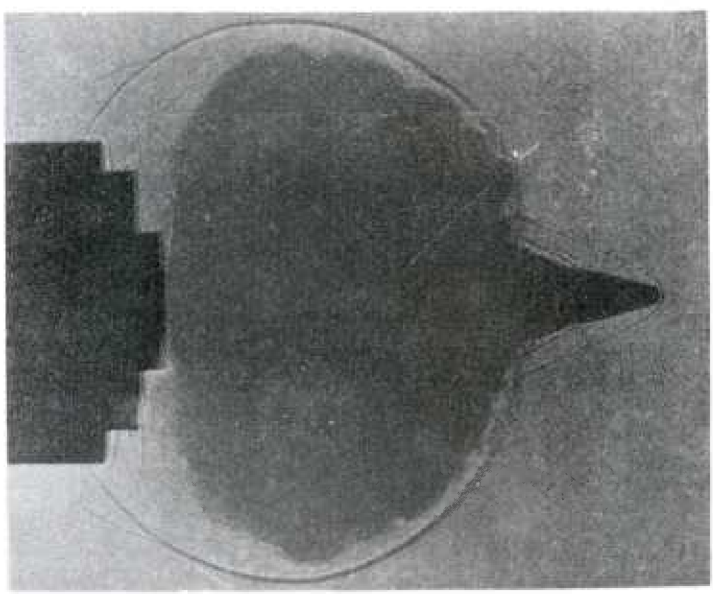


b. Evacuated Tube

Figure 4. Comparison of Muzzle Flow Development - Example 2

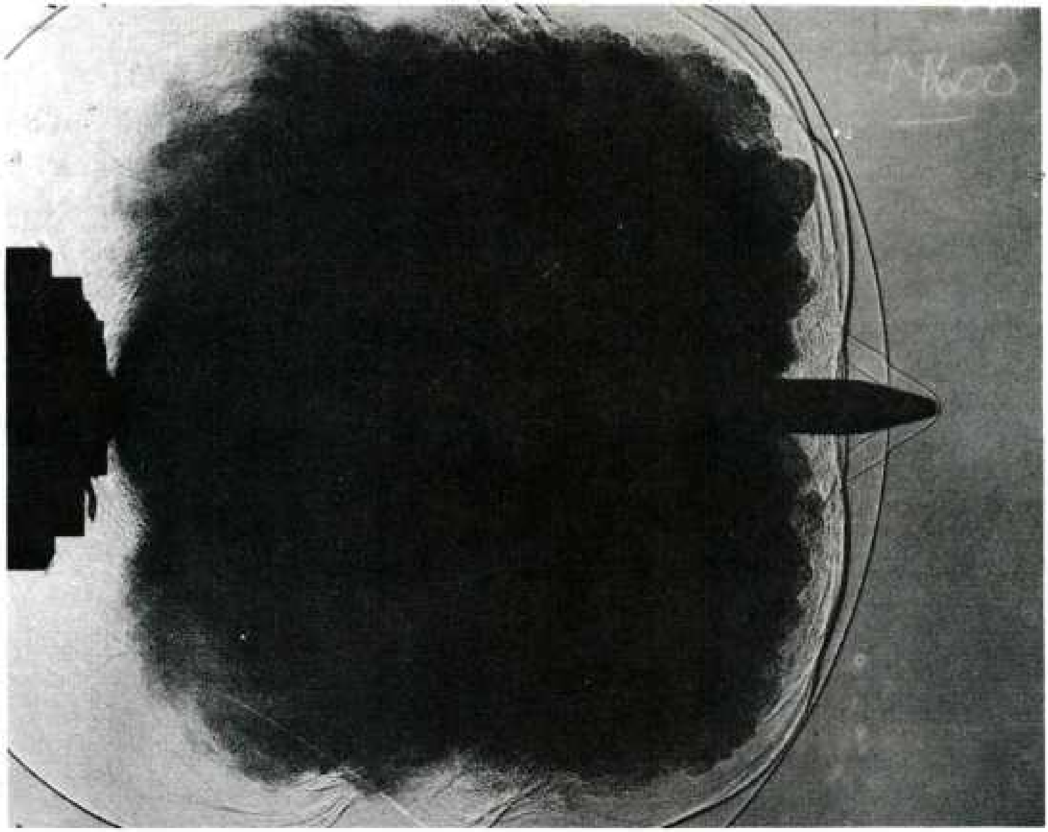


a. Atmospheric Tube

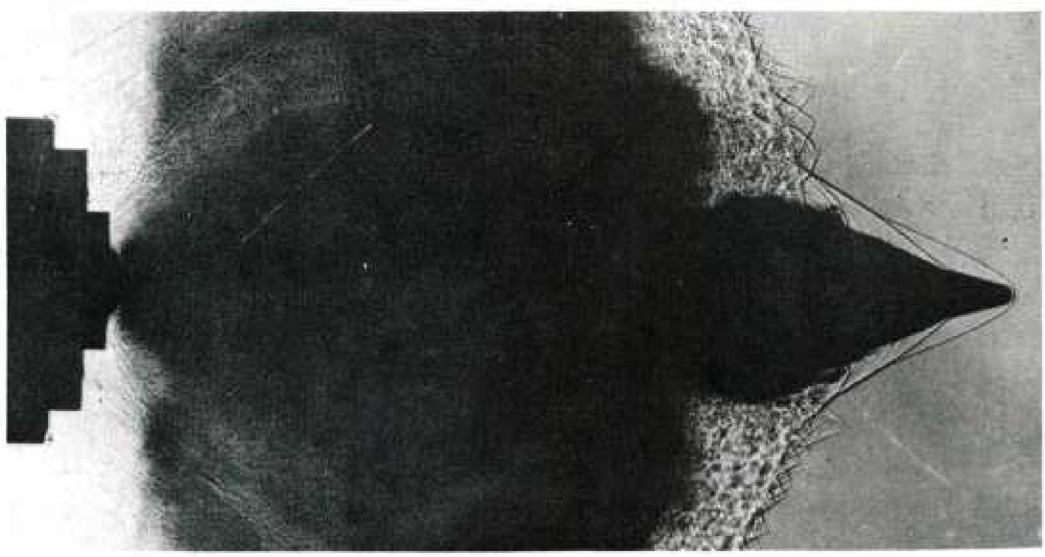


b. Evacuated Tube

Figure 5. Comparison of Muzzle Flow Development - Example 3



a. Atmospheric Tube



b. Evacuated Tube

Figure 6. Comparison of Muzzle Flow Development - Example 4

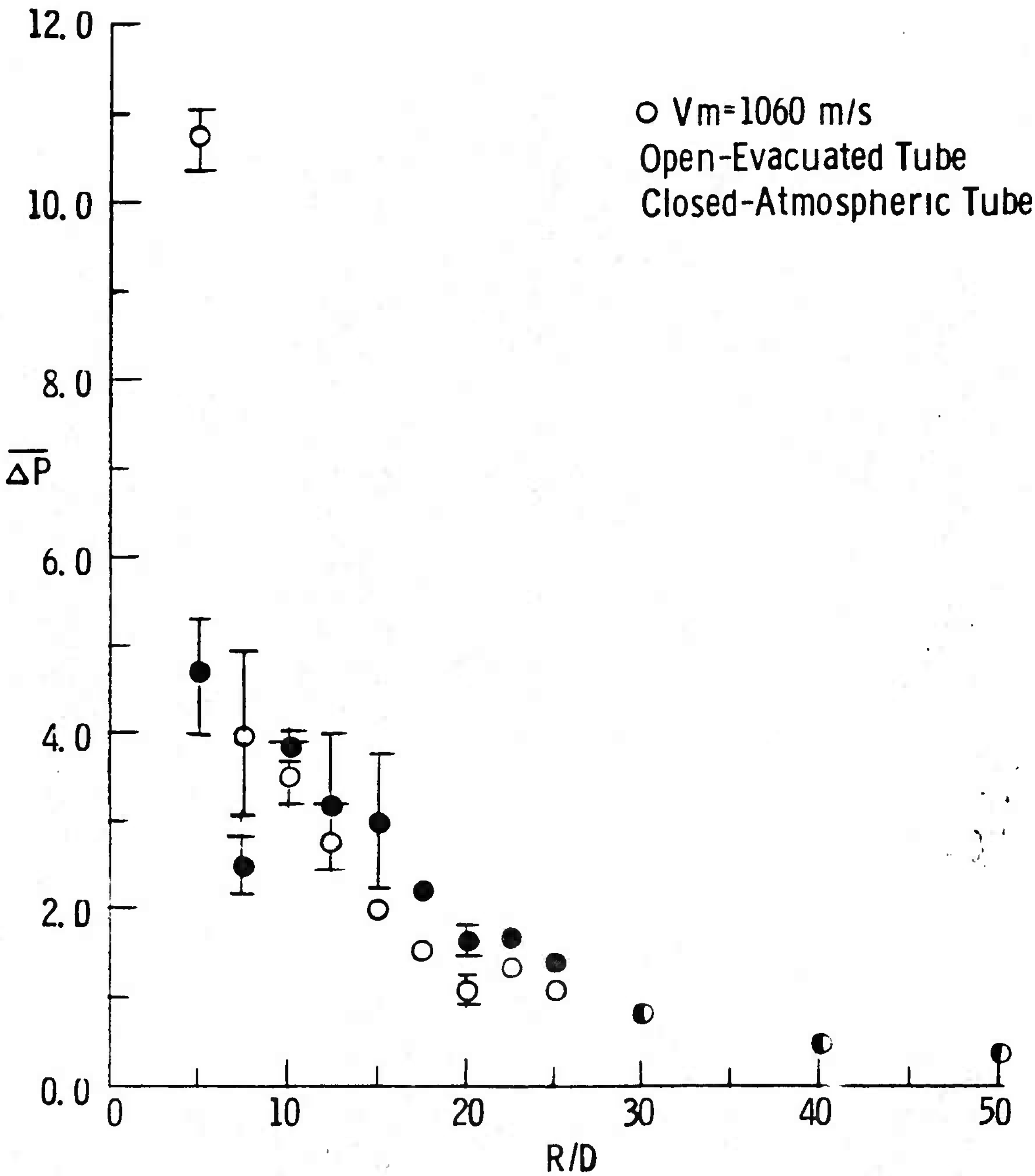



Figure 7. Peak Overpressure Along a $\phi$ = 10° Radial

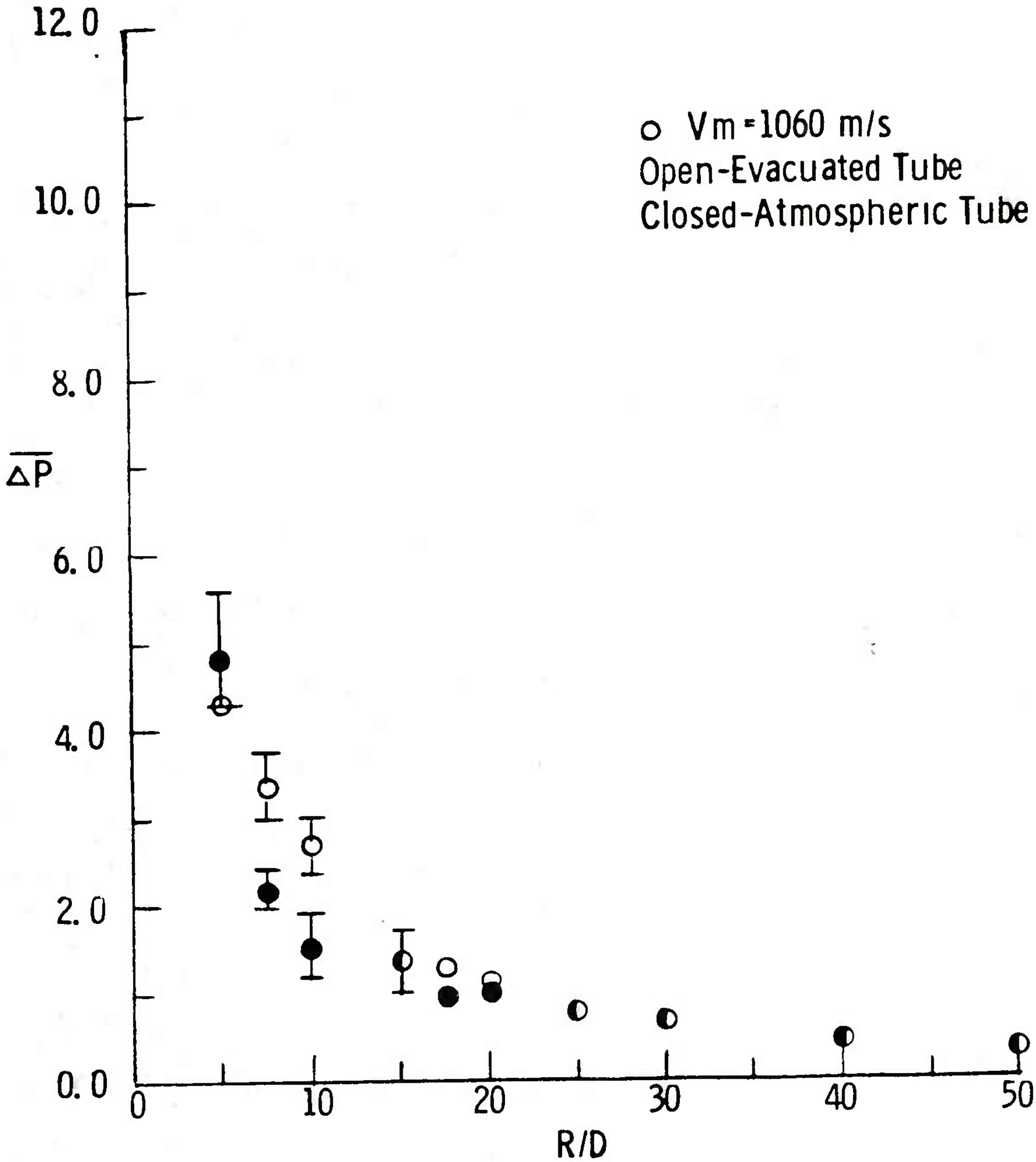



Figure 8. Peak Overpressure Along a $\phi$ = 45° Radial

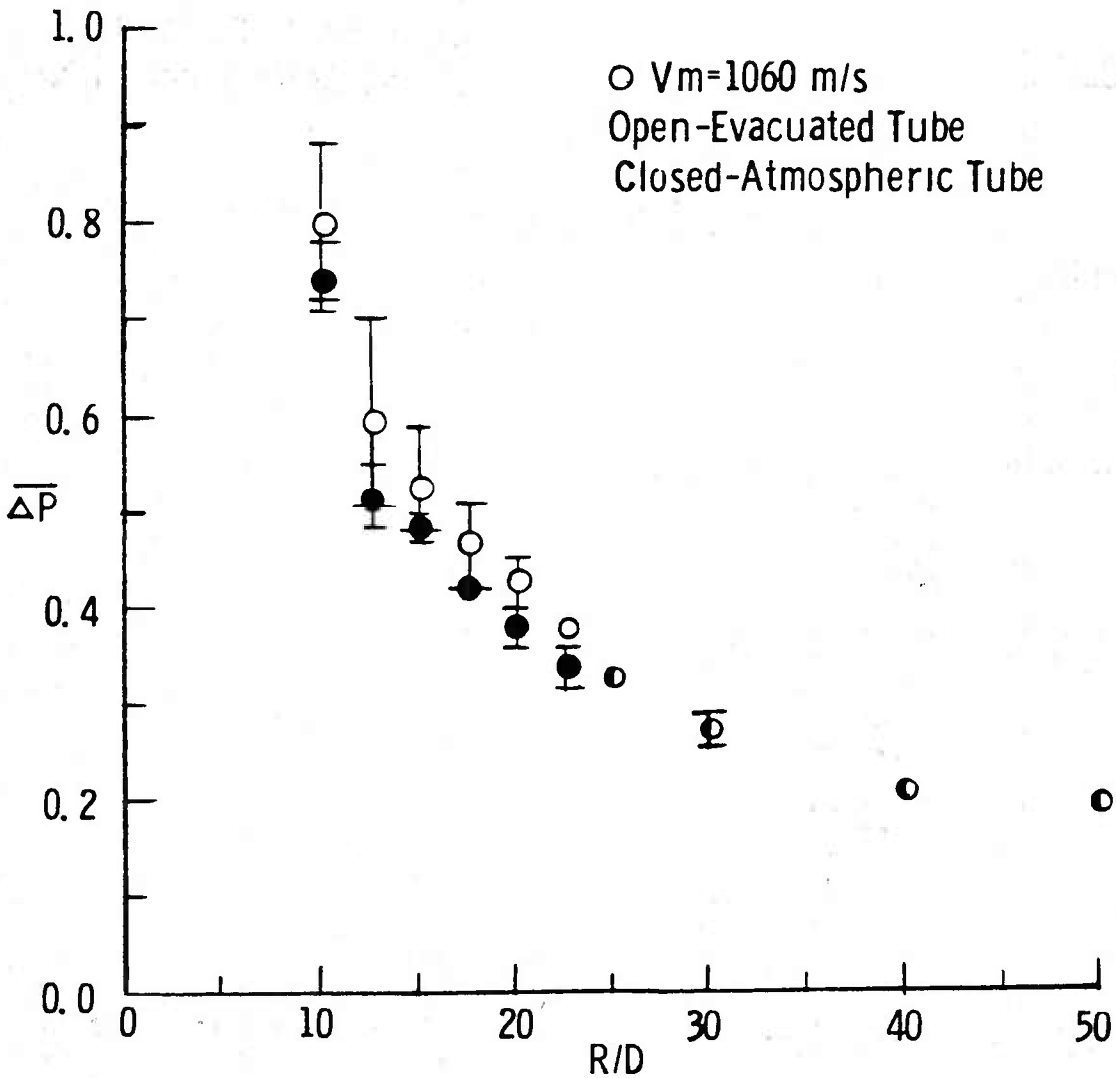



Figure 9. Peak Overpressure Along a $\phi$ = 90° Radial

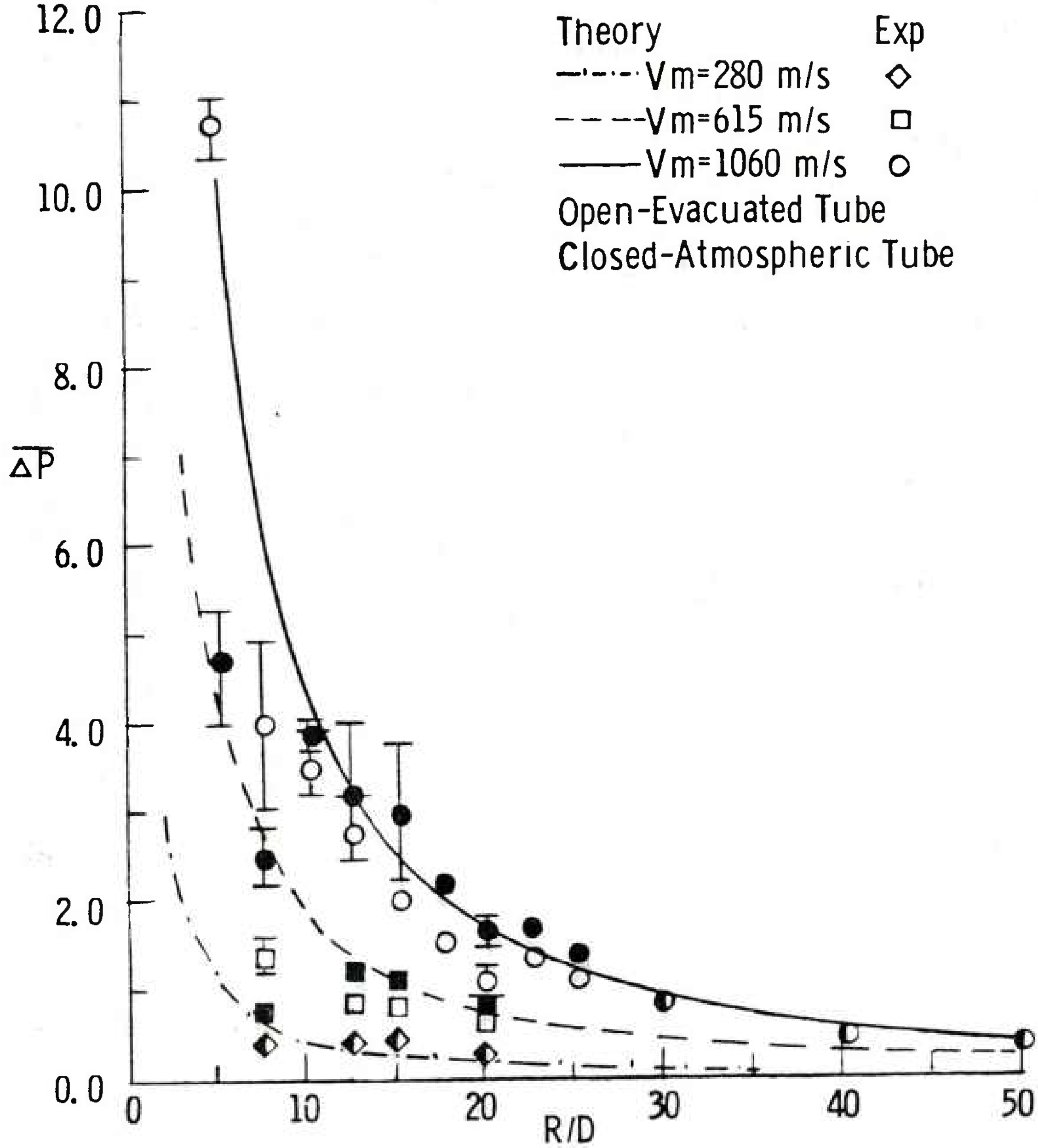



Figure 10a. Comparison of the Predictions of Erdos and DelGuidice with Experimental Results for the Peak Overpressure Along a $\phi = 10°$ Radial

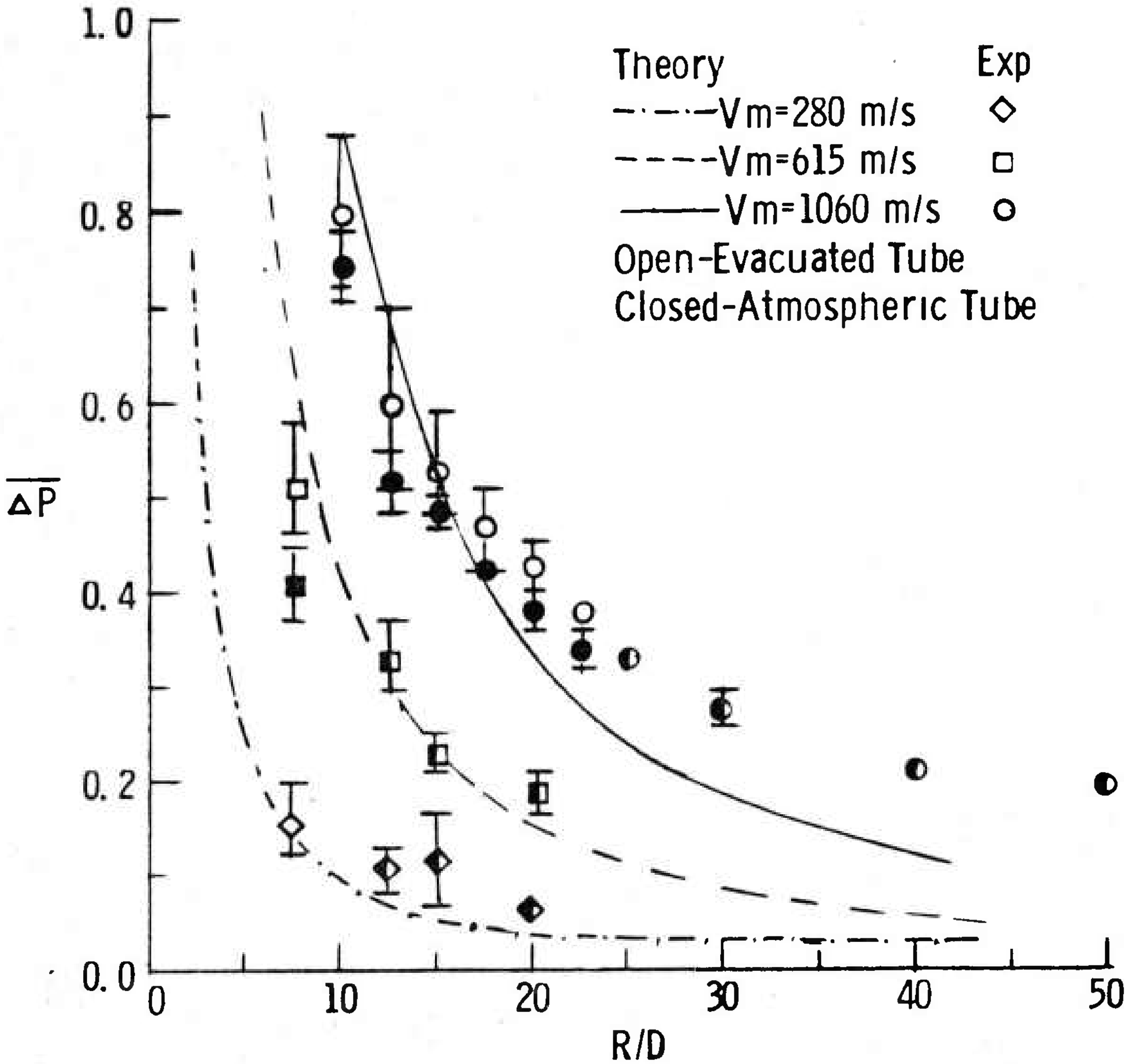



Figure 10b. Comparison of the Predictions of Erdos and DelGuidice with Experimental Results for the Peak Overpressure Along a $\phi = 90°$ Radial

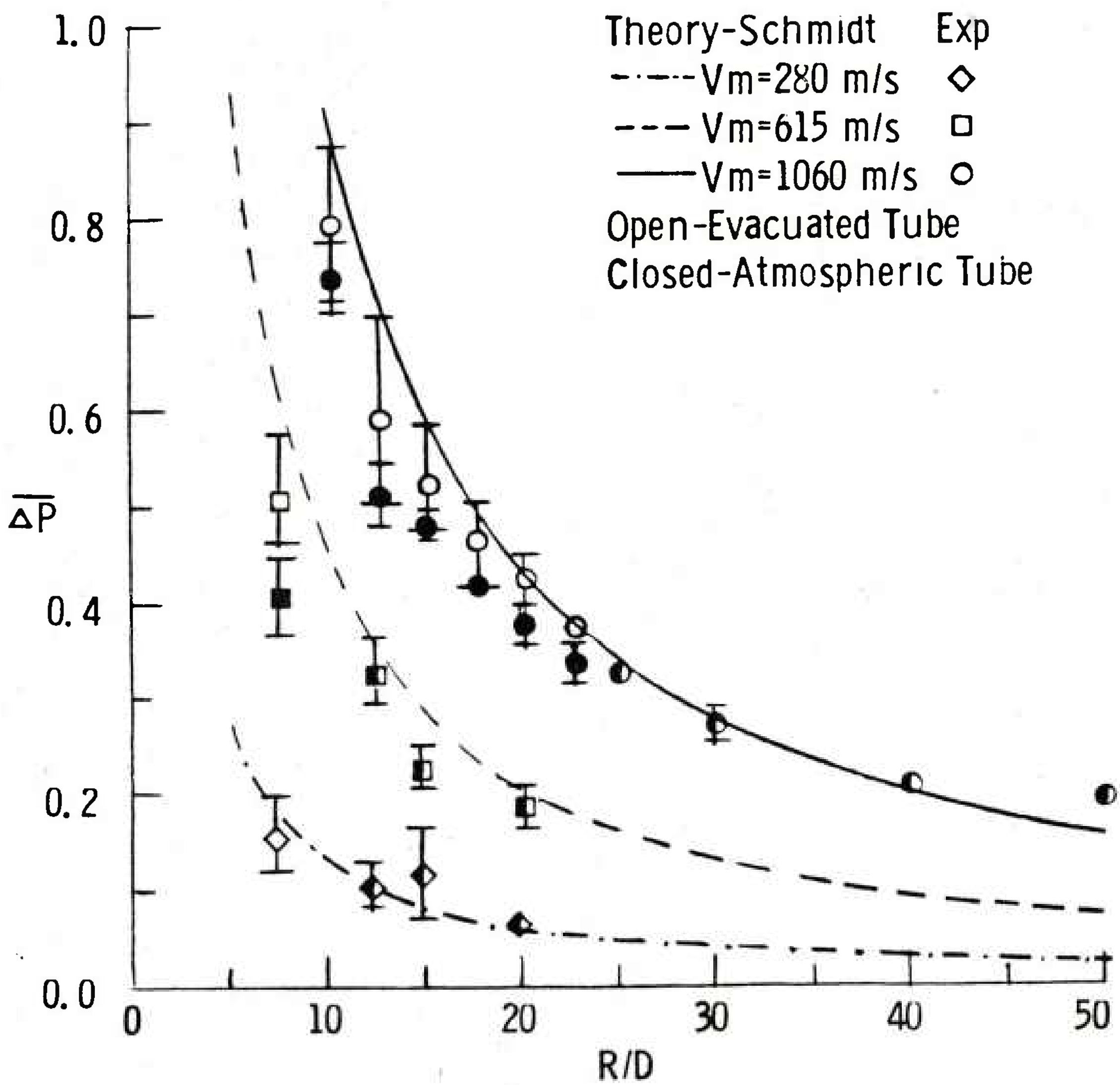



Figure 11. Comparison of the Predictions of Schmidt with Experimental Results for the Peak Overpressure Along a $\phi$ = 90° Radial

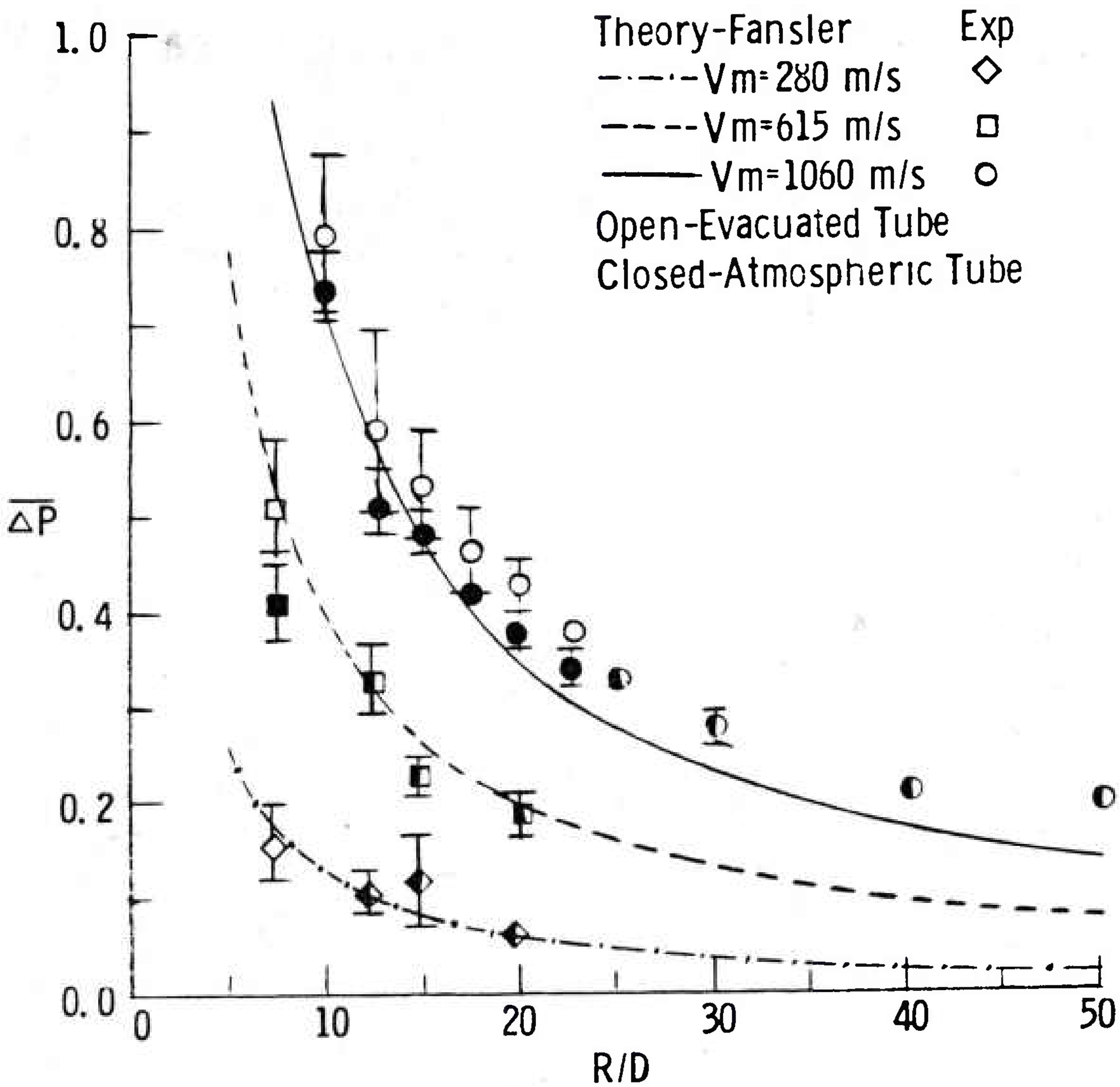



Figure 12. Comparison of the Predictions of Fansler with Experimental Results for the Peak Overpressure Along a $\phi$ = 90° Radial

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## LIST OF SYMBOLS

| | |
|---|---|
| $c$ | scale length |
| $c'$ | stretched scale length |
| $e$ | specific energy |
| $p$ | pressure |
| $p_\infty$ | atmospheric pressure |
| $\overline{\Delta p}$ | overpressure |
| $r$ | radial location |
| $R$ | gas constant |
| $T_{ad}$ | adiabatic flame temperature |
| $x_{ns}$ | stabilized location of Mach disk |
| $\gamma$ | ratio of specific heats |
| $\phi$ | azimuthal angle |

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